APPLICATION

OF

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FOR

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ON

# TEM DUAL-MODE RECTANGULAR DIELECTRIC WAVEGUIDE BANDPASS FILTER



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## BACKGROUND OF THE INVENTION

The present invention relates to a bandpass filter, and particularly, to a TEM dual-mode rectangular-planar dielectric waveguide bandpass filter.

## DESCRIPTION OF THE PRIOR ART

In recent years, marked advances in miniaturization of communication terminals, typically mobile phones, has been achieved thanks to miniaturization of the various components incorporated therein. One of the most important components incorporated in a communication terminal is a filter component.

As one type of filter component, TEM dual-mode dielectric waveguide filters are known (A. C. Kundu and I. Awai, "Low-Profile Dual-Mode BPF Using Square Dielectric Disk Resonator," Proceedings of the 1997 Chugoku-region Autumn Joint Conference of 5 Institutes, Hiroshima, Japan, Oct. 1997, Page 272). Since the TEM dual-mode dielectric waveguide filters acts as two resonators, i.e., two different modes of the resonator have the same resonant frequency, it can be used as small and high performance bandpass filter.

However, since the TEM dual-mode dielectric waveguide filter of the above-mentioned type is electrically connected to a printed circuit board by the wires, there is a problem that it occupies relatively wide area. Further, since the electrodes to which the wires are to be connected are disposed on the side surfaces of the dielectric block, for thin type it is difficult to obtain sufficient external circuit coupling and/or it is difficult to perform a wire bonding.

Moreover, since the TEM dual-mode dielectric waveguide filter of the

above-mentioned type has the removed portion on the metal plate which is floating for controlling the coupling, there is further problem that the radiation loss increases with increasing the area of the removed portion so as to enhance the coupling.

## SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide an improved TEM dual-mode dielectric waveguide bandpass filter.

Another object of the present invention is to provide a very thin TEM dual-mode dielectric waveguide bandpass filter.

Further object of the present invention is to provide a TEM dual-mode dielectric waveguide bandpass filter which requires small area for mounting.

Still further object of the present invention is to provide a TEM dual-mode dielectric waveguide bandpass filter having sufficient external circuit coupling.

Still further object of the present invention is to provide a TEM dual-mode dielectric waveguide bandpass filter in which the radiation loss is decreased.

The above and other objects of the present invention can be accomplished by a bandpass filter of dual-mode comprising a dielectric block having a top surface, a bottom surface and first to fourth side surfaces, a first metal plate to be in a floating state substantially entirely formed on the top surface of the dielectric block, a second metal plate to be grounded formed on the bottom surface of the dielectric block, and means for providing a coupling between the dual-mode.

According to the pres nt invention, because the top surface of the

dielectric block is substantially entirely covered with the first metal plate to be in a floating state, the radiation loss can be reduced.

In a preferred aspect of the present invention, the providing means is achieved by a removed portion exposing a part of the bottom surface of the dielectric block.

In another preferred aspect of the present invention, the providing means is achieved by a coupling control stub formed on the bottom surface of the dielectric block and physically connected to the second metal plate.

In still another preferred aspect of the present invention, the providing means is achieved by a third removed portion exposing still another part of the bottom surface of the dielectric block.

In a further preferred aspect of the present invention, the bandpass filter further comprises a first exciting electrode and a second exciting electrode formed on the bottom surface of the dielectric block.

According to this preferred aspect of the present invention, because the exciting electrodes are disposed on the bottom surface of the dielectric block, the thickness there of the dielectric block and the area for mounting can be reduced. Moreover, because the sufficient external circuit coupling can be obtained, very thin shape and broadband operation can be achieved simultaneously.

In another preferred aspect of the present invention, the bandpass filter further comprises a first exciting electrode formed on the first side surface of the dielectric block and a second exciting electrode formed on the second side surface adjacent to the first side surface of the dielectric block.

The above and other objects of the present invention can be also accomplished by a bandpass filter of dual-mode comprising a dielectric

block having a top surface, a bottom surface and first to fourth side surfaces, a first metal plate formed on the top surface of the dielectric block, a second metal plate formed on the bottom surface of the dielectric block, first and second exciting electrodes formed on the bottom surface of the dielectric block, and means for providing a coupling between the dual-mode.

According to the present invention, because the exciting electrodes are disposed on the bottom surface of the dielectric block, the thickness there of the dielectric block and the area for mounting can be reduced. Moreover, because the sufficient external circuit coupling can be obtained, very thin shape and broadband operation can be achieved simultaneously.

In a preferred aspect of the present invention, the providing means is achieved by a removed portion exposing a part of the bottom surface of the dielectric block.

In another preferred aspect of the present invention, the providing means is achieved by a coupling control stub formed on the bottom surface of the dielectric block and physically connected to the second metal plate.

In still another preferred aspect of the present invention, the providing means is achieved by a third removed portion exposing still another part of the bottom surface of the dielectric block.

The above and other objects and features of the present invention will become apparent from the following description made with reference to the accompanying drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic perspective view from top side showing a bandpass filter 10 that is a preferred embodiment of the present invention.

Figure 2 is a schematic plan view from bottom side showing the bandpass filter 10.

Figure 3 is a schematic perspective view showing a TEM dual-mode rectangular-planar dielectric waveguide resonator 20.

Figure 4 is a schematic perspective view showing the TEM dual-mode rectangular-planar dielectric waveguide resonator 20 having a removed portion 24 on a metal plate 23.

Figure 5 is a schematic perspective view showing a capacitor 30 for exciting the TEM dual-mode rectangular-planar dielectric waveguide resonator 20.

Figure 6 is a conceptual diagram to form the bandpass filter 10 by combining the TEM dual-mode rectangular-planar dielectric waveguide resonator 20, and the capacitor 30 and a spacer 40.

Figure 7 is a graph showing the relationship between the length $d$ of the edge of the removed portion 16 and an even mode resonant frequency $f_{even}$ and an odd mode resonant frequency $f_{odd}$.

Figure 8 is a graph showing the relationship between the length $d$ of the edge of the removed portion 16 and a coupling constant $k$.

Figure 9 is a schematic plan view from bottom side showing the bandpass filter 10 where the length $d$ of the edge of the removed portion 16 is 1.41 mm.

Figure 10 is graph showing the frequency characteristic curve of the bandpass filter 10 shown in Figure 9.

Figure 11 is a schematic plan view showing the example that the removed portion 16 is positioned at upper-right of the metal plate 13.

Figure 12 is a schematic plan view showing the example that the removed portion 16 is positioned at lower-left of the metal plate 13.

Figure 13 is a schematic plan view showing the example that the removed portion 16 is positioned at lower-right of the metal plate 13.

Figure 14 is a schematic plan view showing the example that the removed portion 16 is a sector form.

Figure 15 is a schematic plan view showing the example that the removed portion 16 is a rectangular.

Figure 16 is a schematic plan view showing the example that the removed portion 16 of rectangular is positioned at inner of the metal plate 13.

Figure 17 is a schematic plan view showing the example that the removed portion 16 of circular is positioned at inner of the metal plate 13.

Figure 18 is a schematic plan view showing the example that two removed portions 16 are employed.

Figure 19 is a schematic plan view showing another example that two removed portions 16 are employed.

Figure 20 is a schematic perspective view from top side showing a bandpass filter 50 that is another preferred embodiment of the present invention.

Figure 21 is a schematic plan view from bottom side showing the bandpass filter 50.

Figure 22 is a graph showing the relationship between the length $l$ of the edge of the coupling control stub 56 and an even mode resonant frequency $f_{even}$ and an odd mode resonant frequency $f_{odd}$.

Figure 23 is a graph showing the relationship between the length $l$ of the edge of the coupling control stub 56 and a coupling constant $k$.

Figure 24 is a schematic plan view from bottom side showing the bandpass filter 50 where the length $l$ of the edge of th coupling control

stub 56 is 0.36 mm.

Figure 25 is graph showing the frequency characteristic curve of the bandpass filter 50 shown in Figure 24.

Figure 26 is a schematic plan view showing the example that the coupling control stub 56 is a triangular.

Figure 27 is a schematic plan view showing the example that the coupling control stub 56 is a circular.

Figure 28 is a schematic plan view showing the example that both the coupling control stub 56 and the removed portions 16 are employed.

Figure 29 is a schematic perspective view from top side showing a bandpass filter 60 that is a further preferred embodiment of the present invention.

Figure 30 is a schematic plan view from bottom side showing the bandpass filter 60.

Figure 31 is graph showing the frequency characteristic curve of the bandpass filter 60 shown in Figures 29 and 30.

Figure 32 is a schematic perspective view from top side showing a bandpass filter 70 that is a further preferred embodiment of the present invention.

Figure 33 is a schematic plan view from bottom side showing the bandpass filter 70.

Figure 34 is a schematic perspective view from top side showing a bandpass filter 80 that is a further preferred embodiment of the present invention.

Figure 35 is a schematic plan view from bottom side showing the bandpass filter 80.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

Preferred embodiments of the present invention will now be explained with reference to the drawings.

Figure 1 is a schematic perspective view from top side showing a bandpass filter 10 that is a preferred embodiment of the present invention. Figure 2 is a schematic plan view from bottom side showing the bandpass filter 10.

As shown in Figures 1 and 2, a bandpass filter 10 that is a preferred embodiment of the present invention is constituted of a dielectric block 11 and various metal plates formed on the surface thereof. The dielectric block 11 is made of dielectric material whose dielectric constant $\square_r = 33$, and has the shape of a rectangular prism whose length, width, and thickness are 5.3 mm, 5.3 mm, and 0.5 mm. That is, the dielectric block 11 has no holes or surface irregularities.

A metal plate 12 is formed on the top surface of the dielectric block 11. A metal plate 13 and exciting electrodes 14 and 15 are formed on the bottom surface of the dielectric block 11. As shown in Figure 1, the metal plate 12 is formed on the entire top surface of the dielectric block 11, so that the dimension of the metal plate 12 is 5.3 mm × 5.3 mm square. As shown in Figure 2, the dimension of the metal plate 13 is 4.6 mm × 4.6 mm square along the edge 11a and the edge 11b adjacent to the edge 11a of the bottom surface of the dielectric block 11 having a removed portion 16 of triangular positioned at the corner 11ab formed by the edges 11a and 11b where the edge of the removed portion 16 measures *d*. The exciting electrode 14 is located along the edge 11a and the edge 11c opposite to the edge 11b and the dimension of the exciting electrode 14 measures 0.5 mm × 4.4 mm rectangular. The exciting electrode 15 is located along the

edge 11b and the edge 11d opposite to the edge 11a and the dimension of the exciting electrode 15 measures 0.5 mm × 4.4 mm rectangular.

As shown in Figure 2, the metal plate 13 and the exciting electrode 14 are prevented from contacting each other by 0.2 mm gap. Similarly, the metal plate 13 and the exciting electrode 15 are prevented from contacting each other by 0.2 mm gap.

In actual use, the metal plate 12 formed on the top surface of the dielectric block 11 is floating and the metal plate 13 formed on the bottom surface of the dielectric block 11 is grounded. One of the exciting electrodes 14 and 15 is used as an input electrode, and the other is used as an output electrode.

The metal plates 12 and 13 and the exciting electrodes 14 and 15 are made of silver. However, the present invention is not limited to using silver and other kinds of metal can be used instead. It is preferable to use a screen printing method to form them on the surfaces of the dielectric block 11.

No metal plate or electrode is formed on the remaining surfaces of the dielectric block 11, which therefore constitute open ends. That is, no metal plate or electrode is formed any side surfaces of the dielectric block 11. Thus, the bandpass filter 10 can be fabricated by metallizing the top and bottom surfaces of the dielectric block 11.

According to the above described structure, the bandpass filter 10 of this preferred embodiment acts as a TEM dual-mode rectangular-planar dielectric waveguide bandpass filter.

The principle of the bandpass filter 10 will now be explained.

Figure 3 is a schematic perspective view showing a TEM dual-mode rectangular-planar dielectric waveguide resonator 20.

As shown in Figure 3, the TEM dual-mode rectangular-planar dielectric waveguide resonator 20 is constituted of a dielectric block 21 whose bottom surface is $a \times a$ square and whose thickness is $t$, a metal plate 22 formed on the entire top surface of the dielectric block 21 and a metal plate 23 formed on the entire bottom surface of the dielectric block 21. The metal plate 22 formed on the top surface of the dielectric block 21 is floating and the metal plate 23 formed on the bottom surface of the dielectric block 21 is grounded. Remaining four side surfaces are open to the air.

In the TEM dual-mode rectangular-planar dielectric waveguide resonator 20 having above described structure has two propagation directions, i.e., along $x$ and $y$-direction. Since the length along $x$-direction and the length along $y$-direction of the dielectric block 21 are the same as each other, dominant resonant frequencies based on the propagation along $x$-direction and $y$-direction are substantially coincident. Therefore, the TEM dual-mode rectangular-planar dielectric waveguide resonator 20 acts as two resonators (dual-modes) having the same dominant resonant frequency from electrical point of view. However, since there is no coupling between dual-modes, the TEM dual-mode rectangular-planar dielectric waveguide resonator 20 does not act as a filter.

Coupling between dual-modes can be provided by destroying the symmetry of the resonator structure of each mode in order to acts the TEM dual-mode rectangular-planar dielectric waveguide resonator 20 as a filter.

Figure 4 is a schematic perspective view showing the TEM dual-mode rectangular-planar dielectric waveguide resonator 20 having a removed portion 24 on a metal plate 23. The dielectric block 21 is exposed at the removed portion 24.

As shown in Figure 4, the symmetry of the resonator structure of each mode can be destroyed by forming the removed portion 24 removing a part of the metal plate 23 formed on the bottom surface of the dielectric block 21. It is preferable to locate the removed portion 24 at the corner of the metal plate 23 as shown in Figure 4. Because the symmetry of the resonator structure of each mode is greatly destroyed with increasing the area of the removed portion 24, the coupling between dual-modes increases with increasing the area of the removed portion 24. As set out above, a filter function can be added to the TEM dual-mode rectangular-planar dielectric waveguide resonator 20 by forming the removed portion 24 on the metal plate 23 to destroy the symmetry of the resonator structure of each mode.

The method for exciting the TEM dual-mode rectangular-planar dielectric waveguide resonator 20 will now be explained.

Figure 5 is a schematic perspective view showing a capacitor 30 for exciting the TEM dual-mode rectangular-planar dielectric waveguide resonator 20.

As shown in Figure 5, the capacitor 30 is constituted of a dielectric block 31 whose thickness is $t$, a metal plate 32 formed on the entire top surface of the dielectric block 31 and a metal plate 33 formed on the entire bottom surface of the dielectric block 31. The metal plate 32 formed on the top surface of the dielectric block 31 is a metal plate to be connect to the metal plate 22 formed on the top surface of the dielectric block 21. The metal plate 33 formed on the bottom surface of the dielectric block 31 is the exciting electrode. Remaining four side surfaces are open to the air.

A bandpass filter can be configured by combining the capacitor 30 to

the TEM dual-mode rectangular-planar dielectric waveguide resonator 20. In this case, a dielectric block for a spacer is required between the TEM dual-mode rectangular-planar dielectric waveguide resonator 20 and the capacitor 30 to prevent the metal plate 23 formed on the bottom surface of the dielectric block 21 and the metal plate 33 formed on the bottom surface of the dielectric block 31 from connecting with each other.

Figure 6 is a conceptual diagram to form the bandpass filter 10 by combining the TEM dual-mode rectangular-planar dielectric waveguide resonator 20, and the capacitor 30 and a spacer 40. It is worth noting that Figure 6 is a conceptual diagram so that the bandpass filter 10 is not actually fabricated by combine physical components 20, 30 and 40. Actually, the bandpass filter 10 can be fabricated by metallizing the top and bottom surfaces of the dielectric block 11 as a single component.

As shown in Figure 6, in the bandpass filter 10 by conceptually combining the components 20, 30 and 40, the radiation loss from the top surface of the dielectric block is small because the top surface of the dielectric block is entirely covered with the metal plate. The structure of the bottom surface is already shown in Figure 2. Specifically, the metal plate 23 shown in Figure 4 is used as the metal plate 13, the metal plates 33 shown in Figure 5 is used as the exciting electrodes 14 and 15.

This is the principle of the bandpass filter 10. When the bandpass filter 10 is mounted on the printed circuit board, the metal plate 13 of the bandpass filter 10 is directly connected to the ground electrode formed on the printed circuit board by a solder or the like and the exciting electrodes 14 and 15 of the bandpass filter 10 are is directly connected to the input/output electrodes formed on the printed circuit board by a solder or the like. That is, the bandpass filter 10 of this embodiment can be used

as a SMD (Surface Mount Device). Thus, this embodiment makes the thickness of the bandpass filter 10 small and makes the area for mounting the bandpass filter 10 small.

In order to widen the bandwidth (passing bandwidth) of the bandpass filter 10, increasing the external circuit coupling (excitation coupling) is effective. The external circuit coupling capacitance $C$ can be calculated using the following equation.

$$C = \frac{\varepsilon_0 \varepsilon_r \mathrm{A}}{t} \qquad (1)$$

Where, $\varepsilon_0$ is the permittivity of the air, $\varepsilon_r$ is the relative permittivity of the material of the dielectric block 11, $A$ is each of the surface area of the exciting electrodes 14 and 15, and $t$ is the thickness of the dielectric block 11.

From equation (1), when the material of the dielectric block 11 is decided, the value of the external circuit coupling capacitance $C$ can be increased by increasing the surface area $A$ of the exciting electrodes 14 and 15 and/or decreasing the thickness $t$ of the dielectric block 11.

However, the overall size of the bandpass filter 10 increases with increasing the surface area $A$. Therefore, in order to increase the external circuit coupling capacitance $C$, it is preferable to decrease the thickness $t$ of the dielectric block 11 is effective. Decreasing the thickness $t$ of the dielectric block 11 means decreasing the thickness of the bandpass filter 10.

According to this embodiment, very thin (0.5 mm) dielectric block 11 is used and the exciting electrodes 14 and 15 are disposed on th bottom

surface of the dielectric block 11 taking above described into consideration.

Figure 7 is a graph showing the relationship between the length $d$ of the edge of the removed portion 16 and an even mode resonant frequency $f_{even}$ and an odd mode resonant frequency $f_{odd}$.

As shown in Figure 7, the difference between the even mode resonant frequency $f_{even}$ and the odd mode resonant frequency $f_{odd}$ increases with increasing the length $d$ of the edge of the removed portion 16, whereas the even mode resonant frequency $f_{even}$ and the odd mode resonant frequency $f_{odd}$ are the same when the length $d$ is 0 mm, i.e., without removed portion. This means that the symmetry of the resonator structure of each mode destroys with increasing the length $d$ of the edge of the removed portion 16.

Further, although the even mode resonant frequency $f_{even}$ has very little dependence upon the length $d$ of the edge of the removed portion 16, the odd mode resonant frequency $f_{odd}$ markedly increases with increasing the length $d$. This implies that the coupling between dual-mode caused by the removed portion 16 is inductive.

The coupling constant $k$ between dual-mode can be represented by the following equation.

$$k = \frac{f_{even}^2 - f_{odd}^2}{f_{even}^2 + f_{odd}^2} \qquad (2)$$

The relationship between the length $d$ of the edge of the removed portion 16 and the coupling constant $k$ can be obtained by referring to the equation (2).

Figure 8 is a graph showing the relationship betw en the length $d$ of

the edge of the removed portion 16 and a coupling constant $k$.

As is apparent from Figure 8, the coupling constant $k$ exponentially increases with increasing length $d$ of the edge of the removed portion 16, whereas the coupling constant $k$ is zero when the length $d$ is 0 mm, i.e., without removed portion. Thus, a desired coupling constant $k$ can be obtained by controlling length $d$ of the edge of the removed portion 16. In order to obtain the coupling constant $k$ being 0.036, the length $d$ of the edge of the removed portion 16 should be 1.41 mm. In this case, an external quality factor becomes about 27.

Figure 9 is a schematic plan view from bottom side showing the bandpass filter 10 where the length $d$ of the edge of the removed portion 16 is 1.41 mm. Figure 10 is graph showing the frequency characteristic curve of the bandpass filter 10 shown in Figure 9.

In Figure 10, S11 represents a reflection coefficient, and S21 represents a transmission coefficient. As shown in Figure 10, the center resonant frequency of the bandpass filter 10 shown in Figure 9 is approximately 5.8 GHz and its 3-dB bandwidth is approximately 280 MHz. According to the bandpass filter 10 of this embodiment, very wide bandwidth can be obtained. Further, attenuation poles appear at approximately 4.1 GHz and 5.2 GHz in lower side of the passing band; attenuation pole appear at approximately 6.3 GHz in higher side of the passing band. Therefore, both of the lower and higher edges of the passing band of the frequency characteristics are sharpened.

Because, as described above, in the bandpass filter 10 according to this embodiment, the exciting electrodes 14 and 15 are formed on the bottom surface of the dielectric block 11, the bandpass filter 10 can be directly mounted on the printed circuit board without using any wir s.

That is, the bandpass filter 10 can be used as a SMD so that the area for mounting thereof can be reduced. Therefore, in the bandpass filter 10 according to this embodiment, very thin shape and broadband operation can be achieved simultaneously.

Further, according to the bandpass filter 10, because the metal plate 12 is formed on the top surface of the dielectric block 11 and thickness of the dielectric block 11 is small, the radiation loss can be reduced. therefore, high unloaded quality factor ($Q_0$) can be obtained.

Moreover, according to the bandpass filter 10, because the attenuation poles appear at both higher side and lower side, a sharp frequency characteristics can be obtained.

In this embodiment, although the removed portion 16 is positioned at the corner 11ab of the edge 11a and 11b, it is not limited that the removed portion 16 is positioned at the corner 11ab but it can be positioned at another portion.

Figures 11 to 13 are schematic plan views showing the example that the removed portion 16 is positioned at another corner. The removed portion 16 is positioned at upper-right of the metal plate 13 in Figure 11, at lower-left of the metal plate 13 in Figure 12, and at lower-right of the metal plate 13 in Figure 13. The coupling between dual-mode is also provided in the example shown in Figures 11 to 13 because the symmetry of the resonator structure of each mode is destroyed by the removed portion 16.

Further, in this embodiment, although the removed portion 16 is triangular, it is not limited that the removed portion 16 is triangular but it can be another shape insofar as the symmetry of the resonator structure of each mode is destroyed.

Figures 14 and 15 are schematic plan views showing the example that the removed portion 16 has another shape. In Figure 14, the removed portion 16 is a sector form; in Figure 15, the removed portion 16 is a rectangular. The coupling between dual-mode is also provided in the example shown in Figures 14 and 15 because the symmetry of the resonator structure of each mode is destroyed by the removed portion 16.

Moreover, in this embodiment, although the removed portion 16 is positioned at the corner of the metal plate 13, it is not limited that the removed portion 16 is positioned at the corner but it can be positioned at another portion insofar as the symmetry of the resonator structure of each mode is destroyed.

Figures 16 and 17 are schematic plan views showing the example that the removed portion 16 is positioned at inner of the metal plate 13. In Figure 16, the removed portion 16 of rectangular is positioned at inner of the metal plate 13 close to the upper-left corner; in Figure 17, the removed portion 16 of circular is positioned at inner of the metal plate 13 close to the lower-left corner. The coupling between dual-mode is also provided in the example shown in Figures 16 and 17 because the symmetry of the resonator structure of each mode is destroyed by the removed portion 16.

Furthermore, in this embodiment, although only one removed portion 16 is formed, it is not limited that the number of the removed portion 16 is one but the number of the removed portions 16 can be plurality insofar as the symmetry of the resonator structure of each mode is destroyed.

Figures 18 and 19 are schematic plan views showing the example that the plurality of removed portion 16 are formed on the metal plate 13.

In Figure 18, two removed portions 16-1 and 16-2 of triangular are positioned at the upper-left corner and lower-right corner, respectively; in Figure 19, two removed portions 16-3 and 16-4 of rectangular are positioned at the upper-right corner and lower-left corner, respectively. The inductive coupling and capacitive coupling between dual-mode are also provided in the example shown in Figures 18 and 19, respectively, because the symmetry of the resonator structure of each mode is destroyed by the removed portions 16-1 to 16-4.

Another preferred embodiment of the present invention will now be explained.

Figure 20 is a schematic perspective view from top side showing a bandpass filter 50 that is another preferred embodiment of the present invention. Figure 21 is a schematic plan view from bottom side showing the bandpass filter 50.

As shown in Figures 20 and 21, the bandpass filter 50 that is another preferred embodiment of the present invention is constituted of a dielectric block 51 and various metal plates formed on the surface thereof. The dielectric block 51 is the same as the dielectric block 11 used in the bandpass filter 10 of above described embodiment. Thus, the dielectric block 51 is made of dielectric material whose dielectric constant $\square_r = 38$, and has the shape of a rectangular prism whose length, width, and thickness are 5.3 mm, 5.3 mm, and 0.5 mm.

A metal plate 52 is formed on the top surface of the dielectric block 51. A metal plate 53, exciting electrodes 54 and 55 and a coupling control stub 56 are formed on the bottom surface of the dielectric block 51. As shown in Figure 21, the dimension of the metal plate 53 is 4.6 mm × 4.6 mm square along the edge 51a and the edge 51b adjacent to the edge 51a

of the bottom surface of the dielectric block 51. No removed portion is formed on the metal plate 53 different from the bandpass filter 10. The exciting electrode 54 is located along the edge 51a and the edge 51c opposite to the edge 51b and the dimension of the exciting electrode 54 measures 0.5 mm × 4.2 mm rectangular. The exciting electrode 55 is located along the edge 51b and the edge 51d opposite to the edge 51a and the dimension of the exciting electrode 55 measures 0.5 mm × 4.2 mm rectangular.

The coupling control stub 56 is located adjacent at the corner 51cd of the edge 51c and edge 51d being in contact with the metal plate 53. The dimension of the coupling control stub 56 measures 0.4 mm × $l$ rectangular.

The metal plate 53 and the exciting electrode 54 are prevented from contacting each other by 0.2 mm gap. Similarly, the metal plate 53 and the exciting electrode 55 are prevented from contacting each other by 0.2 mm gap. No metal plate or electrode is formed on the remaining surfaces of the dielectric block 51, which therefore constitute open ends.

In actual use, the metal plate 52 formed on the top surface of the dielectric block 51 is floating and the metal plate 53 formed on the bottom surface of the dielectric block 51 is grounded similar to the bandpass filter 10. One of the exciting electrodes 54 and 55 is used as an input electrode, and the other is used as an output electrode.

According to the above described structure, although the bandpass filter 50 of this preferred embodiment acts as a TEM dual-mode rectangular-planar dielectric waveguide bandpass filter, the symmetry of the resonator structure of each mode is destroyed by the coupling control stub 56. In other words, the coupling control stub 56 gives coupling

between dual-mode. The coupling between dual-mode increases with increasing the area of the coupling control stub 56 because the magnitude of the destroying the symmetry increases with increasing the area of the coupling control stub 56.

Figure 22 is a graph showing the relationship between the length $l$ of the edge of the coupling control stub 56 and an even mode resonant frequency $f_{even}$ and an odd mode resonant frequency $f_{odd}$.

As shown in Figure 22, the difference between the even mode resonant frequency $f_{even}$ and the odd mode resonant frequency $f_{odd}$ increases with increasing the length $l$ of the coupling control stub 56, whereas the even mode resonant frequency $f_{even}$ and the odd mode resonant frequency $f_{odd}$ are the same when the length $l$ is 0 mm, i.e., without coupling control stub. This means that the symmetry of the resonator structure of each mode destroys with increasing the length $l$ of the coupling control stub 56.

Further, although the odd mode resonant frequency $f_{odd}$ has very little dependence upon the length $l$ of the coupling control stub 56, the even mode resonant frequency $f_{even}$ markedly decreases with increasing the length $l$. This implies that the coupling between dual-mode caused by the coupling control stub 56 is capacitive.

The coupling constant $k$ between dual-mode can be represented by the equation (2) explained earlier.

Figure 23 is a graph showing the relationship between the length $l$ of the coupling control stub 56 and a coupling constant $k$.

As is apparent from Figure 23, the coupling constant $k$ linearly increases with increasing length $l$ of the coupling control stub 56, whereas the coupling constant $k$ is zero when the length $l$ is 0 mm, i.e., without

coupling control stub. Thus, a desired coupling constant $k$ can be obtained by controlling length $l$ of the coupling control stub 56. In order to obtain the coupling constant $k$ being 0.032, the length $l$ of the coupling control stub 56 should be 0.36 mm.

Figure 24 is a schematic plan view from bottom side showing the bandpass filter 50 where the length $l$ of the edge of the coupling control stub 56 is 0.36 mm. Figure 25 is graph showing the frequency characteristic curve of the bandpass filter 50 shown in Figure 24.

In Figure 25, S11 represents a reflection coefficient, and S21 represents a transmission coefficient. As shown in Figure 25, the center resonant frequency of the bandpass filter 50 shown in Figure 24 is approximately 5.66 GHz and its 3-dB bandwidth is approximately 250 MHz. Thus, according to the bandpass filter 50 of this embodiment, very wide bandwidth can be obtained. Further, attenuation pole appear at approximately 4.4 GHz so that the lower edge of the passing band of the frequency characteristics is sharpened.

The bandpass filter 50 has effects not only the effects obtained by the bandpass filter 10 of the above described embodiment but also an effect that the radiation loss is more effectively reduced.

In this embodiment, although the coupling control stub 56 is rectangular, it is not limited that the coupling control stub 56 is rectangular but it can be another shape insofar as the symmetry of the resonator structure of each mode is destroyed.

Figures 26 and 27 are schematic plan views showing the example that the coupling control stub 56 has another shape. In Figure 26, the coupling control stub 56 is a triangular; in Figure 27, the coupling control stub 56 is a circular. The coupling between dual-mode is also provided in

the example shown in Figures 26 and 27 because the symmetry of the resonator structure of each mode is destroyed by the coupling control stub 56.

Further, in this embodiment, although the symmetry of the resonator structure of each mode is destroyed by only using the coupling control stub 56, the removed portion 16 shown in Figures 9 and 11 to 19 can be employed in addition.

Figure 28 is a schematic plan view showing the example that both the coupling control stub 56 and the removed portions 16 are employed. In the example shown in Figure 28, the coupling control stub 56 of rectangular is formed and the removed portions 16 of triangular is formed on the upper-right corner of the metal plate 53. The capacitive coupling between dual-mode is also provided in the example shown in Figure 28 because the symmetry of the resonator structure of each mode is destroyed by the coupling control stub 56 and the removed portions 16.

A further preferred embodiment of the present invention will now be explained.

Figure 29 is a schematic perspective view from top side showing a bandpass filter 60 that is a further preferred embodiment of the present invention. Figure 30 is a schematic plan view from bottom side showing the bandpass filter 60.

As shown in Figures 29 and 30, the bandpass filter 60 that is a further preferred embodiment of the present invention is constituted of a dielectric block 61 and various metal plates formed on the surfaces thereof. The dielectric block 61 is the same as the dielectric blocks 11 and 51 used in the bandpass filters 10 and 50 of above described embodiments. Thus, the dielectric block 61 is made of dielectric material whose dielectric

constant $\square_r = 33$, and has the shape of a rectangular prism whose length, width, and thickness are 5.3 mm, 5.3 mm, and 0.5 mm.

A metal plate 62 is formed on the top surface of the dielectric block 61. A metal plate 63 and exciting electrodes 64 and 65 are formed on the bottom surface of the dielectric block 61. As shown in Figure 30, the dimension of the metal plate 63 is 4.6 mm × 4.6 mm square along the edge 61a and the edge 61b adjacent to the edge 61a of the bottom surface of the dielectric block 61 having a removed portion 66 of triangular positioned at the corner 61ab formed by the edges 61a and 61b similar to the bandpass filter 10. As shown in Figure 30, the exciting electrode 64 is located along the edge 61c opposite to the edge 61b and the dimension of the exciting electrode 64 measures 0.5 mm × 2.6 mm rectangular. The exciting electrode 65 is located along the edge 61d opposite to the edge 61a and the dimension of the exciting electrode 65 measures 0.5 mm × 2.6 mm rectangular. Further, the exciting electrode 64 is apart from the edge 61a and the exciting electrode 65 is apart from the edge 61b different from the above described embodiments. As shown in Figure 30, the distances between the exciting electrode 64 and the edge 61a and the exciting electrode 65 and the edge 61b are defined by clearance *s*.

The metal plate 63 and the exciting electrode 64 are prevented from contacting each other by 0.2 mm gap. Similarly, the metal plate 63 and the exciting electrode 65 are prevented from contacting each other by 0.2 mm gap. No metal plate or electrode is formed on the remaining surfaces of the dielectric block 61, which therefore constitute open ends.

In actual use, the metal plate 62 formed on the top surface of the dielectric block 61 is floating and the metal plate 63 formed on the bottom surface of the dielectric block 61 is ground d similar to the bandpass filter

10. One of the exciting electrodes 64 and 65 is used as an input electrode, and the other is used as an output electrode.

Figure 31 is graph showing the frequency characteristic curve of the bandpass filter 60 shown in Figures 29 and 30.

In Figure 31, S11 represents a reflection coefficient, and S21 represents a transmission coefficient. As shown in Figure 31, the frequencies of the attenuation poles drastically vary with changing clearance *s*, whereas the center resonant frequency of the bandpass filter 60 and its 3-dB bandwidth do not substantially vary with changing clearance *s*. Specifically, the frequencies of the attenuation poles shift high with increasing the clearance *s*; the frequencies of the attenuation poles shift low with decreasing the clearance *s*. Further, the attenuation level at the lower attenuation band decreases and the attenuation level at the higher attenuation band increases with increasing the clearance *s*; the attenuation level at the lower attenuation band increases and the attenuation level at the higher attenuation band decreases with decreasing the clearance *s*. This phenomenon is caused by the fact that a direct coupling between the exciting electrodes 64 and 65 increases with increasing the clearance *s*. Thus, the clearance *s* should be controlled based on a desired characteristics.

The bandpass filter 60 has effects not only the effects obtained by the bandpass filter 10 of the above described embodiment but also an effect that the characteristics at the attenuation band can be controlled by simple method.

In this embodiment, although the removed portion 66 of triangular is formed on the upper-left corner of the metal plate 63, the position, shape and number of the removed portion 66 are not limited as explained with

reference to Figures 11 to 19.

Further, in this embodiment, although the symmetry of the resonator structure of each mode is destroyed by using the removed portion 66, the symmetry can be destroyed by using the coupling control stub similar to the bandpass filter 50 shown in Figures 20 and 21.

A further preferred embodiment of the present invention will now be explained.

Figure 32 is a schematic perspective view from top side showing a bandpass filter 70 that is a further preferred embodiment of the present invention. Figure 33 is a schematic plan view from bottom side showing the bandpass filter 70.

As shown in Figures 32 and 33, the bandpass filter 70 that is a further preferred embodiment of the present invention is constituted of a dielectric block 71 and various metal plates formed on the surface thereof. The dielectric block 71 is the same as the dielectric blocks 11, 51 and 61 used in the bandpass filters 10, 50 and 60 of above described embodiments except that the corner formed by the top surface and adjacent two side surfaces thereof is removed. A surface 76 of rectangular is formed at the removed corner. An edge 76a formed on one side surface of the dielectric block 71 and an edge 76b formed on the other side surface of the dielectric block 71 have the same length.

A metal plate 72 is formed on the top surface of the dielectric block 71. A metal plate 73 and exciting electrodes 74 and 75 are formed on the bottom surface of the dielectric block 71. As shown in Figure 33, no removed portion is formed on the metal plate 73.

In actual use, the metal plate 72 formed on the top surface of the dielectric block 71 is floating and the metal plate 73 formed on the bottom

surface of the dielectric block 71 is grounded similar to the bandpass filter 10. One of the exciting electrodes 74 and 75 is used as an input electrode, and the other is used as an output electrode.

Because, as described above, in the bandpass filter 70 according to this embodiment, the corner of the dielectric block 71 is removed so as to destroy the symmetry of the resonator structure of each mode, similar effects of above described embodiments can be obtained. It is worth noting that the removed portion on the metal plate 73 and/or the coupling control stub can formed in this embodiment.

A further preferred embodiment of the present invention will now be explained.

Figure 34 is a schematic perspective view from top side showing a bandpass filter 80 that is a further preferred embodiment of the present invention. Figure 35 is a schematic plan view from bottom side showing the bandpass filter 80.

As shown in Figures 34 and 35, the bandpass filter 80 that is a further preferred embodiment of the present invention is constituted of a dielectric block 81 and various metal plates formed on the surface thereof. The dielectric block 81 is the same as the dielectric blocks 11, 51 and 61 used in the bandpass filters 10, 50 and 60. That is, the dielectric block 81 is a rectangular prism.

A metal plate 82 is formed on the entire top surface of the dielectric block 81. A metal plate 83 is formed on the entire bottom surface of the dielectric block 81 except at removed portions 86 to 88. As shown in Figure 35, the removed portion 86 is positioned at the corner 81ab formed by the edges 81a and 81b adjacent to the edge 81a of the bottom surface of the dielectric block 81; the r moved portion 87 is positioned at the center

of the edge 81c opposite to the edge 81b of the bottom surface of the dielectric block 81; and the removed portion 88 is positioned at the center of the edge 81d opposite to the edge 81a of the bottom surface of the dielectric block 81.

As shown in Figure 34, an exciting electrode 84 is formed on the side surface 81e of the dielectric block 81 being in contact with the edge 81c; an exciting electrode 85 is formed on the side surface 81f of the dielectric block 81 being in contact with the edge 81d. These exciting electrodes 84 and 85 are prevented from contacting the metal plate 83 by the removed portions 87 and 88, respectively. No metal plate or electrode is formed on the remaining surfaces of the dielectric block 81, which therefore constitute open ends.

In actual use, the metal plate 82 formed on the top surface of the dielectric block 81 is floating and the metal plate 83 formed on the bottom surface of the dielectric block 81 is grounded similar to the bandpass filter 10. One of the exciting electrodes 84 and 85 is used as an input electrode, and the other is used as an output electrode.

In the bandpass filter 80 of this embodiment, although the exciting electrodes 84 and 85 are formed on the side surfaces of the dielectric block 81, the exciting electrodes 84 and 85 can be directly connected to the electrodes formed on the printed circuit board by using a solder or the like without using wires because the exciting electrodes 84 and 85 are in contact with the edges (81c and 81d) of the bottom surface of the dielectric block 81. That is, the bandpass filter 80 can be used as a SMD.

In this embodiment, although the removed portion 86 of triangular is formed on the upper-left corner of the metal plate 83, the position, shape and number of th removed portion 86 are not limited as xplained with

reference to Figures 11 to 19.

Further, in this embodiment, although the symmetry of the resonator structure of each mode is destroyed by using the removed portion 86, the symmetry can be destroyed by removing the corner of the dielectric block 81 similar to the bandpass filter 70 shown in Figure 32.

The present invention has thus been shown and described with reference to specific embodiments. However, it should be noted that the present invention is in no way limited to the details of the described arrangements but changes and modifications may be made without departing from the scope of the appended claims.

For example, in the above described embodiments, the dielectric blocks for the resonators and the evanescent waveguide are made of dielectric material whose dielectric constant $\varepsilon_r$ is 33. However, a material having a different dielectric constant can be used according to purpose.

Further, the dimensions of the dielectric blocks, metal plates and exciting electrodes specified in the above described embodiments are only examples. Dielectric blocks, metal plates and exciting electrodes having different dimensions can be used according to purpose.

Because, as described above, in the bandpass filter according to the present invention, the top surface of the dielectric block is substantially entirely covered with the metal plate of a floating state, the radiation loss can be reduced.

Further, in the case where the exciting electrodes are disposed on the bottom surface of the dielectric block, the thickness thereof and the area for mounting can be reduced. In this case, because the sufficient external circuit coupling can be obtained, very thin shape and broadband operation

can be achieved simultaneously.

Therefore, the present invention provides a bandpass filter that can be preferably utilized in communication terminals such as mobile phones and the like, Wireless LANs (Local Area Networks), and ITS (Intelligent Transport Systems) and the like.